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The Radiation Dose in a Molniya-Type Orbit

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A pair of dosimeters aboard satellites in a Molniya orbit have made measurements of the radiation dose under 0.69 gm/cm^2 of aluminum. The measured dose was substantially less than that predicted by the NASA AE-8 and AP-8 models. The cause of the difference cannot be determined with certainty. One possibility is that AP-8 is in agreement with the observations and that AE-8 leads to a substantial overestimate of the dose due to electrons.

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I. INTRODUCTION

Measurements have been made since August 1983 of the radiation dose encountered by satellites in a Molniya-type orbit. The Molniya orbit is named for the Soviet COMSATS which utilize this orbit. The inclination of the orbit, 63°, is selected such that the argument of perigee does not change. The orbital period, just under 12 hours, is selected such that apogee "hangs" above the same two places on the Earth every day. The period requirement fixes the semi-major axis of the orbit of course and, in order to maximize the "hang time" over the region of interest, perigee height is made as low as possible commensurate with orbital lifetime requirements.

The orbital parameters result in a variety of magnetospheric environments for the satellite ranging from the Southern auroral zone, the equatorial regions of the inner zone with its energetic protons and electrons, the outer zone energetic electrons, the high-latitude plasma sheet, the magnetosheath and, at times, the interplanetary medium. The dosimeter makes a direct measurement of the dose in silicon in a slab geometry under 100 mils of aluminum shielding. The geometry of the spacecraft installation is such that approximately π solid-angle is not heavily shielded; the other 3π is heavily shielded.

In this report, data from two independent measurements will be presented and the implications discussed.

II. DOSIMETER

The dosimeter, built by the Space Sciences Laboratory of The Aerospace Corporation, uses technology proven by flights aboard many USAF and NASA satellites. Each dosimeter consists of two separate, single-detector units. Only one unit is operated at a time; the other serves as a flight spare.

The dosimeter storage register has a capacity of 36 bits. The counts are accumulated directly in binary code, so the total capacity of each dose-monitor channel is 2^{36} counts or 6.87×10^{10} counts. Each count corresponds to 2.7×10^{-6} rads as determined by calibration with radioactive sources. The maximum dose capacity is 1.85×10^{5} rads. The maximum and minimum measurable dose rate is determined by maximum discharge pulse rate (10^{5} pulse/sec) and the system leakage current (1 pulse/500 sec) respectively. The maximum measurable dose rate is 0.27 rads/sec. The minimum detectable dose rate is 5.4×10^{-9} rads/sec (0.17 rad/yr).

III. RESULTS

The dosimeters were flown aboard two satellites. The dosimeters are labeled, for reasons irrelevant to the present discussion, as PL03 and PL04.

Figure 1 gives the daily dose as measured by PL03 from August 1983 to August 1985. A large variation in the daily dose can be seen. Note the three very large peaks late in 1984. These are the largest daily doses seen to date. These peaks are separated by the synodic period of the Sun, and are the result of a high-speed solar-wind stream impinging upon the Earth's magnetosphere.

Figure 2 shows the dose as measured by PL03 and PL04 from February 1985 to February 1986 on the same plot. Similar structure is seen in both measurements but the magnitude of the dose is quite different in the two cases. Note also that the "quiet-time" level in PL03 was flat at the end of the time period whereas for PL04 it was decreasing. These differences were unexpected.

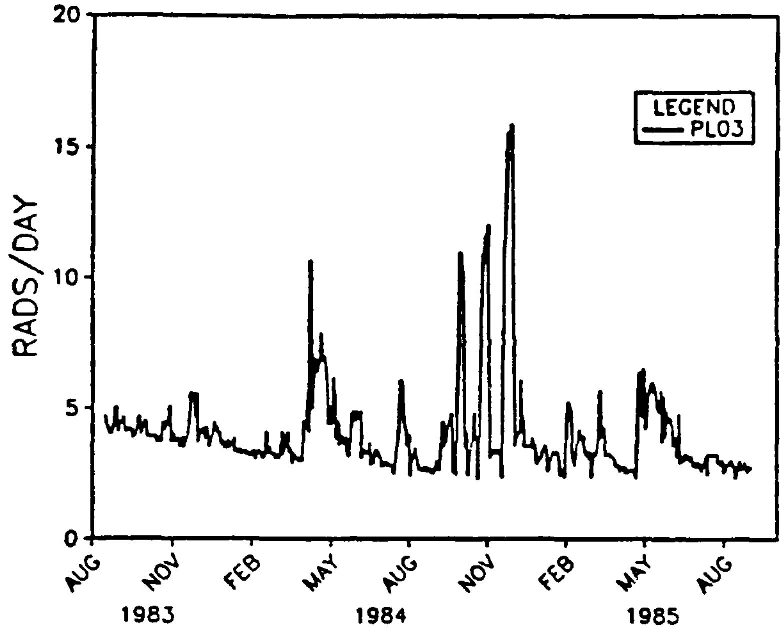

Fig. 1. The Radiation Dose Measured by PL03 is Shown as a Function of Time Between August 1983 and August 1985.

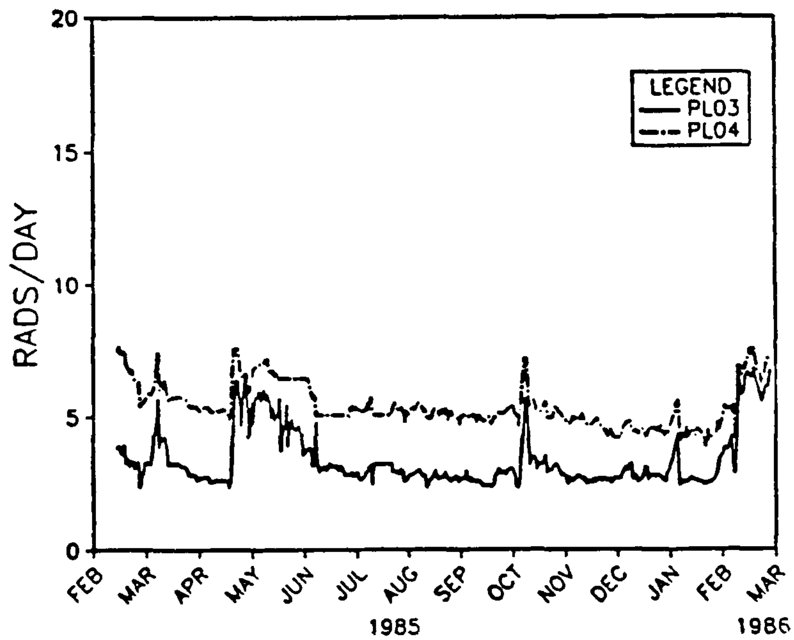

Fig. 2. The Radiation Dose Measured by PL03 and PL04 is Shown as a Function of Time Between February 1985 and February 1986.

Figure 3 shows the run of data from February 1985 until February 1988. This plot shows that the dose from PL04 continued to decline whereas the dose from PL03 began to increase and by late 1986 they became identical.

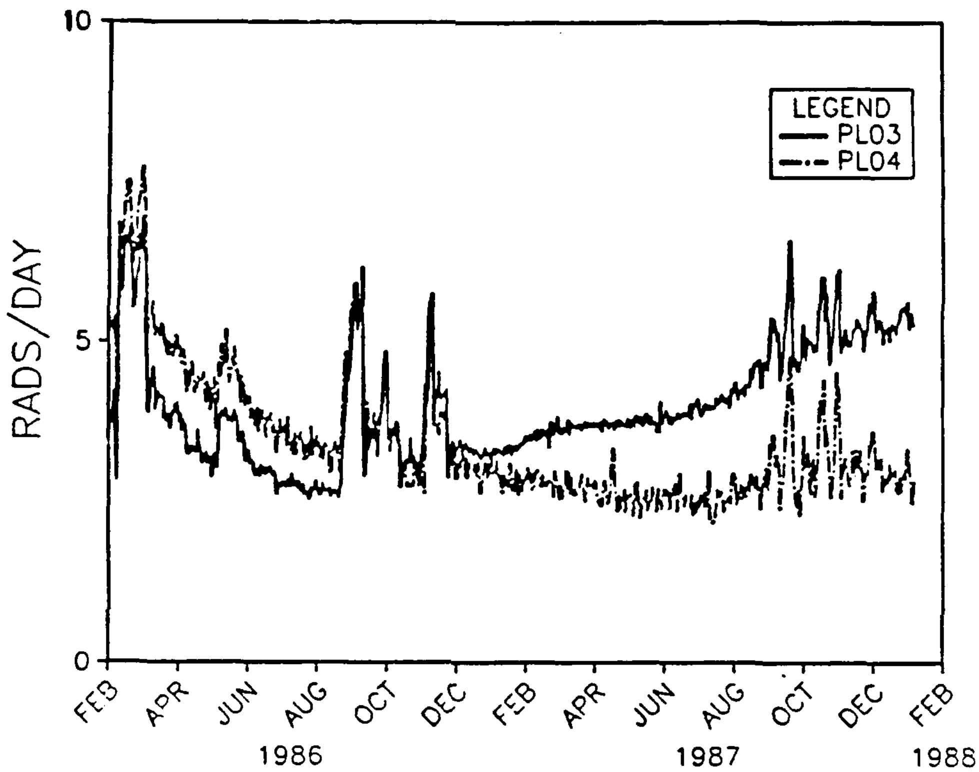

Fig. 3. A Plot Similar to Fig. 2 for the Time Period Between February 1985 and February 1986.

In Fig. 4 the height of perigee is plotted vs. the dose difference between PL04 and PL03. Note that, when the perigee altitudes were identical, the measured daily doses were essentially the same. It is not a longitude effect since the orbital planes were close together and fixed relative to each other. This comparison shows that the initial difference observed in the data from the two dosimeters was due to exposure to a different environment and not due to a difference in the dosimeters themselves. This figure shows that the height of perigee has a strong effect upon the dose experienced by a Molniya satellite.

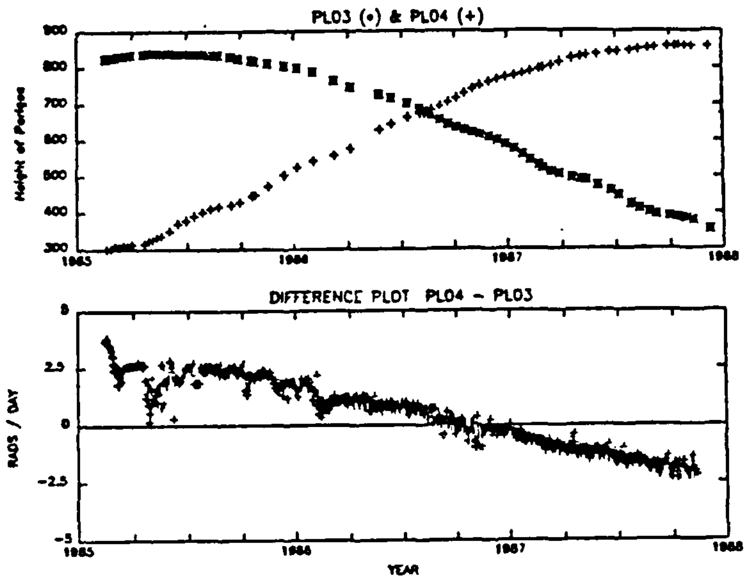

Fig. 4. The Height of Perigee of the Two Satellites. The dose difference is plotted a a function of time.

Figure 5, showing the entire data set for PL03, clearly shows the variation of the quiet-time flux with perigee height.

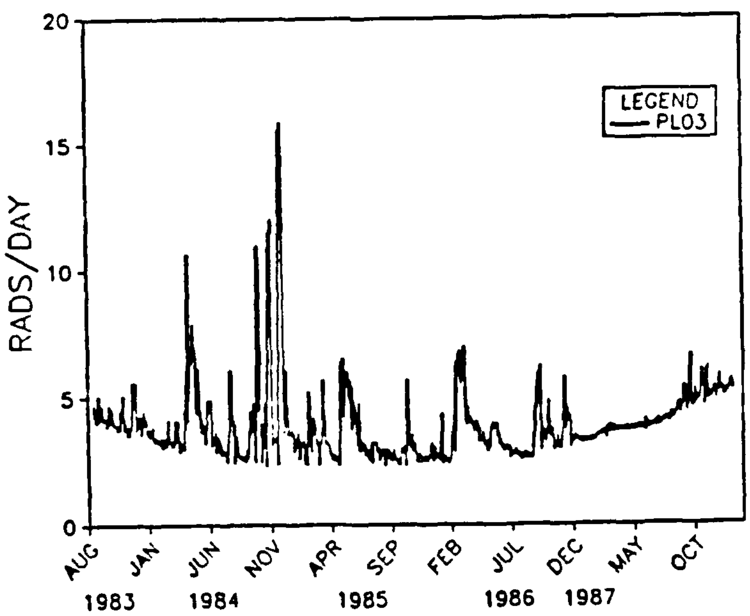

Fig. 5. The Entire Run of Data Presently Available from PL03 is Shown.

IV. MODEL COMPARISON

In Table 1 the calculated dose from the Shielddose code using the NASA AE-8 and AP-8 models as input is compared with the observations for perigee heights of 341nm and 857nm. The actual locations of the orbital planes of the two satellites were used in the calculations; they differed only by 11°. The measured dose has been multipiied by 2 because only ~ 1/2 of the semi-infinite shield was exposed to the ambient environment.

Table 1. Calculated/Measured Dose Comparison

341nm Perigee			857nm Perigee		
Electron & Brems	Proton	Measured*	Electron & Brems	Proton	Measured*
14.3	6.9	8.84	21.1	4.5	5.44
$\underbrace{\qquad\qquad}_{21.2}$			$\underbrace{\qquad\qquad}_{21.1}$		

*The actual measured doses are multiplied by 2 because of the geometry of the dosimeter, see above.

Note that the calculated dose is more than a factor of 2 larger than the measured dose, that electrons provide the largest contribution to the total dose, and that the electron dose is larger at 857nm than at 341nm whereas the proton dose is larger at 341nm than at 857nm.

V. DISCUSSION

Why the large difference between the measured and calculated radiation dose? Gussenhoven et al.[1] have made measurements of the radiation dose in the DMSP orbit which is circular at 450nm and at a 96° inclination. They found that the outer zone plus inner zone electron dose in the DMSP orbit is substantially less than that predicted by NASA model AE-8. For a spherical shield with a thickness of 0.55 gm/cm^2 of aluminum, they find a calculated-to-measured ratio of ~ 6, and for a 1.55 gm/cm^2 shield they find a ratio ~ 9.

Thus, we are led to consider the possibility that the disagreement between the Molniya predictions and measurements is due to an overestimate of the electron dose by the NASA models. Remember that the Molniya shield is 0.69 gm/cm^2 aluminum in a semi-infinite slab geometry.

Let f be the convection factor to bring the measured and observed dose into agreement. Then from Table 1:

$$14.3\, f + 6.9 = 8.84,$$
$$21.1\, f + 4.5 = 5.44.$$

These equations give f = .0814. Thus, the overprediction of the NASA models is 12.3 for the Molniya orbit under the assumption that the discrepancy we observe is due to the NASA electron models alone.

[1] M. S. Gussenhoven, E. G. Mullen, R. C. Filz, D. H. Brantegun, and F. A. Hauser, IEEE Trans. Nucl. Sci. NS-34, 686, 1987.

VI. CONCLUSIONS

1) The dose measurements made in a Molniya orbit suggest that the NASA AE-8 model substantially overpredicts the dose under a ~ 0.69 gm/cm^2 aluminum shield. Note that these measurements do not prove that this is the case, more complex differences between prediction and measurement are possible.

2) The number of large storms, which substantially add to the radiation dose, varied greatly in number and intensity over the mission to date.

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, chemical dynamics, environmental chemistry, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed chemical and excimer laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, microelectronics applications, communication protocols, and computer security.

Electronics Research Laboratory: Microelectronics, solid-state device physics, compound semiconductors, radiation hardening; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; microwave semiconductor devices, microwave/millimeter wave measurements, diagnostics and radiometry, microwave/millimeter wave thermionic devices; atomic time and frequency standards; antennas, rf systems, electromagnetic propagation phenomena, space communication systems.

Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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